Improvement of the lifetime of radio frequency antenna for plasma generation

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At Lawrence Berkeley National Laboratory different antenna protection schemes have been investigated for the radio frequency-driven multicusp ion source. It was found that the antenna lifetime can be greatly enhanced by an additional shielding, which consists of porcelain, quartz or boron nitride. Different antenna configurations and their influence on the plasma generation will be discussed. Antenna life time greater than 500 hours continuous wave operation has been demonstrated in hydrogen plasma using a novel quartz antenna design. [S0034-6748(00)54202-6]

I. INTRODUCTION

Radio frequency (rf) driven multicusp sources are widely used in accelerator laboratories around the world as well as in industry. rf discharge has many advantages compared to filament discharge, high plasma density, tungsten-contamination-free plasma and operation in oxygen filled environments are only a few. Many accelerators and industrial processes require hundreds of hours of un-interrupted operation. In such a long-term operation, the antenna lifetime has been a limiting factor in some cases. Due to the high rf potential of the antenna, sputtering processes caused by the ions from the plasma reduces its lifetime. A possible solution is by coating the antenna with some dielectric material. However, in high power pulsed or continuous wave (cw) operation, the antenna coating may fail. This is because the coating is not perfect everywhere. Any small cracks in the coating may develop into bigger ones and may eventually lead to failure. Some antennas have a lifetime of 50 h, some have failed after a couple of hours. At Lawrence Berkeley National Laboratory we have investigated different rf antenna designs so that it can meet both the source performance and the lifetime requirements. Few solutions were found, namely copper coil antenna sandwiched between two quartz cylinders, boron–nitride shielded copper antenna, single loop antenna, and double tube antenna consisting of titanium or stainless steel tube inside protecting quartz tube. These antennas were tested and compared to the widely used porcelain-coated copper antenna and to a quartz tube antenna with silver wire inside.

II. EXPERIMENTAL SETUP

All experimental measurements were performed in a standard 10 cm diam multicusp source,[1] shown in Fig. 1. The copper plasma chamber has an inner diameter of 10 cm and is surrounded by 20 SmCo magnet columns. Two pairs of magnets in the source back plate enhance the cusp confinement. The gas is introduced to the plasma chamber through a needle valve and the absolute pressure in the source is measured by a capacitance manometer.

The extraction system consists of a plasma electrode with an aperture of 3 mm. The faraday cup was located 5 cm from the grounded second electrode. The faraday cup is magnetically shielded to suppress secondary electrons.

A rf-matching network was used to match the plasma and antenna impedance to the output impedance of the 13.56 MHz rf-amplifier and coaxial transmission line. The terminating impedance typically ranges between 0.5 and 2 Ω, whereas the coaxial transmission line and the output impedance of the rf amplifier are both 50 Ω. The matching network consists of a variable capacitor and an inductor in a series resonance configuration and a variable tap ferrite core transformer. The variable tap transformer serves two functions. First, it electrically isolates the ion source from the amplifier, enabling the source to float at the extraction potential. Second, the turn ratio (which ranges from 5:1 to 8:1) is selected to transform the terminating impedance to 50 Ω. The circuit is tuned to resonance by adjusting the capacitance. Matched

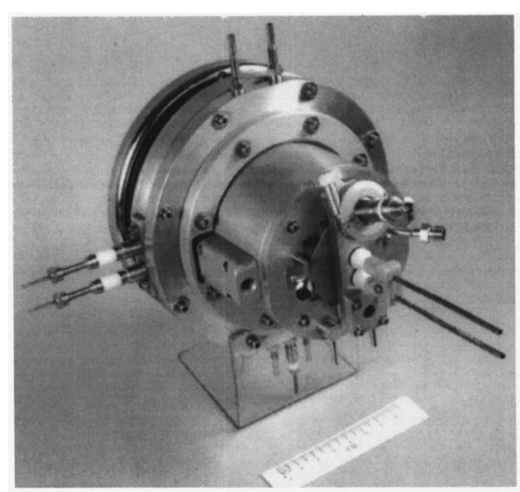

FIG. 1. 10 cm multicusp ion source, similar to one used in the measurements.

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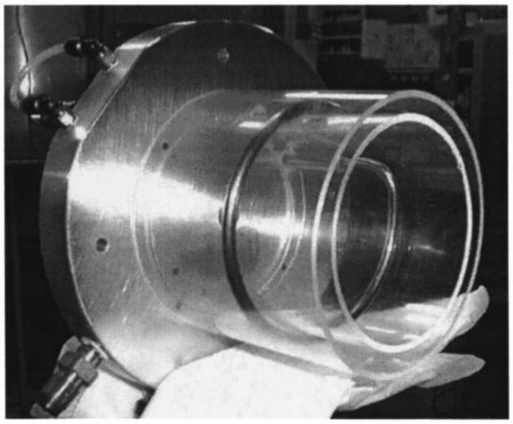

FIG. 2. A bare copper antenna inside two quartz cylinders. The diameter of the outer cylinder is 10 cm.

conditions are indicated by a minimum in the reflected power.

III. DIFFERENT RF ANTENNA CONFIGURATIONS

A. Shielded or coated antennas

Three different types of shielded or coated antennas were tested, namely a porcelain-coated copper coil antenna, a copper coil antenna between ceramic or quartz cylinders,[2] and a copper coil antenna inside a boron nitride casing.

Figure 2 is a picture of a bare copper antenna sandwiched between two quartz cylinders in the back plate of the ion source as shown.

In this arrangement, the antenna is well protected from the plasma, but the small distance between the antenna and the plasma chamber walls induces sparking. Holes will then form on the outer cylinder and the antenna will be destroyed. Another disadvantage is that with only one single large loop, the source efficiency is reduced. This can be seen from Fig. 3, in which the extracted ion current of the small multiturn antenna is compared with those of single turn large diameter antennas. The drop of ion current density is around 20%.

In the lifetime test, the inner cylinder in the double cylinder case is gradually covered with metal from the antenna, thus, further decreasing the performance of the sandwiched antenna setup.

A boron nitride encapsulated antenna does not have arcing problems. On the other hand, boron nitride is a highly

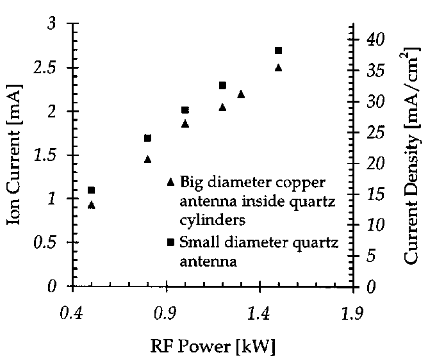

FIG. 3. Comparison between a large single turn antenna performance to a small multiturn antenna. The difference is around 20%.

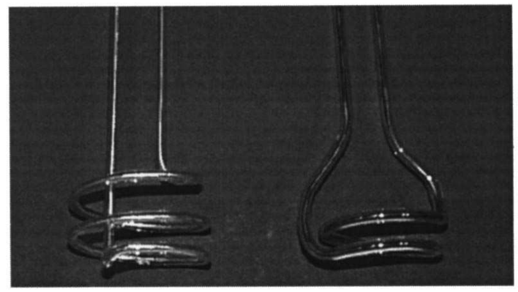

FIG. 4. On the left-hand side quartz antenna with the wire inside, on the right-hand side quartz antenna with the titanium tube inside.

porous material and it takes a long time for the case to outgas. A similar drop in source efficiency is observed in the antenna sandwiched between two cylinders.

B. Quartz tube antenna

Two types of small diameter quartz antennas were tested: a quartz tube that had a silver wire inside and a quartz tube that had a titanium tube inside. Figure 4 is a picture of these two types of antennas.

Small diameter quartz antennas which are installed from the middle of the source back plate reduce damages from sparking. Both of these types of antennas have demonstrated lifetime over 100 h at 2.0 kW cw rf power in the hydrogen plasma. In the case of the titanium tube antenna, well over 500 h of continuing operation has been shown. Figure 5 shows a picture of a titanium tube antenna after 330 h of cw operation at the conditions mentioned above.

The disadvantage of wire type antenna to tube type is that in case of antenna failure, the cooling water, which is flowing inside the quartz tube, leaks to the vacuum. For example, in the case of radioactive ion beam (RIB) production this failure mode is unacceptable due to existence of radioactive elements in the plasma chamber. Titanium tube antenna is structurally more rigid. Thus, antenna failures which are caused by mechanical stresses of the fragile quartz tube are greatly reduced. If for some reason antenna fails during the source operation, only air will be leaked in to the source. From the operational stand point of the source, this failure is much easier to handle compared to water leakage.

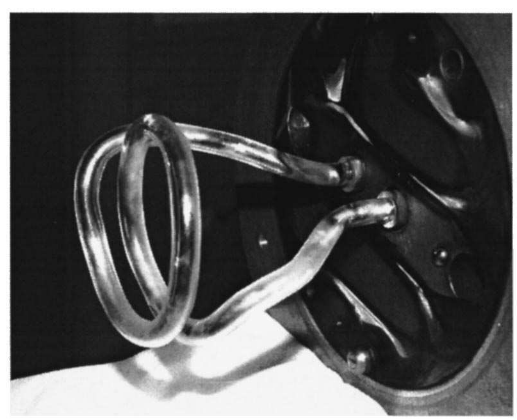

FIG. 5. Titanium tube antenna after 330 h of 2 kW cw operation in hydrogen plasma.

IV. DISCUSSION

In hydrogen, cw discharge new kind of titanium tube antenna has shown good performance and a long lifetime. Further testing is still needed to ensure long a lifetime in more severe conditions, like pulsed, high power operations and operations in heavy ion plasmas. In both cases the stresses to the antenna are greater than in cw hydrogen operation due to either sudden thermal loads or because of sputtering. Sputtering makes the antenna walls thinner. The sputtering effect is especially strong around the antenna legs. This is because arcing can occur in that region. The best way to protect the antenna legs from sputtering is to shield the legs with thick aluminum oxide tubing. Sputtering of the plasma chamber walls can be reduced by using materials such as stainless steel or molybdenum. These further enhancements on antenna lifetime are under investigation.

ACKNOWLEDGMENTS

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[2] J. Peters, Rev. Sci. Instrum. **69**, 992 (1998).